Docket No.
HIT1P025/HSJ9-2003-0084US1

U.S. Patent Application

FOR

GMR ENHANCING SEEDLAYER FOR SELF PINNED SPIN VALVES

Inventor(s):
Mustafa Pinarbasi

Assignee: Hitachi Global Storage Technologies

Silicon Valley IP Group, PC
P.O. Box 721120
San Jose, CA 95172

GMR ENHANCING SEEDLAYER FOR SELF PINNED SPIN VALVES

FIELD OF THE INVENTION

The present invention relates to magnetic heads, and more particularly, this invention relates to read heads having a new seed layer structure that improves signal and/or pinned layer stability.

BACKGROUND OF THE INVENTION

The heart of a computer is an assembly that is referred to as a magnetic disk drive. The magnetic disk drive includes a rotating magnetic disk, write and read heads that are suspended by a suspension arm above the rotating disk and an actuator that swings the suspension arm to place the read and write heads over selected circular tracks on the rotating disk. The read and write heads are directly mounted on a slider that has an air bearing surface (ABS). The suspension arm biases the slider into contact with the surface of the disk when the disk is not rotating but, when the disk rotates, air is swirled by the rotating disk adjacent the ABS of the slider causing the slider to ride on an air bearing a slight distance from the surface of the rotating disk. When the slider rides on the air bearing the write and read heads are employed for writing magnetic impressions to and reading magnetic impressions from the rotating disk. The read and write heads are

connected to processing circuitry that operates according to a computer program to implement the writing and reading functions.

The write head includes a coil layer embedded in first, second and third insulation layers (insulation stack), the insulation stack being sandwiched between first and second pole piece layers. A gap is formed between the first and second pole piece layers by a nonmagnetic gap layer at an air bearing surface (ABS) of the write head. The pole piece layers are connected at a back gap. Current conducted to the coil layer induces a magnetic field into the pole pieces that fringes across the gap between the pole pieces at the ABS. The fringe field or the lack thereof writes information in tracks on moving media, such as in circular tracks on a rotating disk.

In recent read heads a spin valve sensor is employed for sensing magnetic fields from the rotating magnetic disk. The sensor includes a nonmagnetic conductive layer, hereinafter referred to as a spacer layer, sandwiched between first and second ferromagnetic layers, hereinafter referred to as a pinned layer, and a free layer. First and second leads are connected to the spin valve sensor for conducting a sense current therethrough. The magnetization of the pinned layer is pinned perpendicular to an air bearing surface (ABS) of the head and the magnetic moment of the free layer is located parallel to the ABS but free to rotate in response to external magnetic fields. The magnetization of the pinned layer is typically pinned by exchange coupling with an antiferromagnetic layer.

The thickness of the spacer layer is chosen so that shunting of the sense current and a magnetic coupling between the free and pinned layers are minimized. This thickness is typically less than the mean free path of electrons conducted through the

sensor. With this arrangement, a portion of the conduction electrons is scattered by the interfaces of the spacer layer with the pinned and free layers. When the magnetic moments of the pinned and free layers are parallel with respect to one another scattering is minimal and when their magnetic moments are antiparallel scattering is maximized. An increase in scattering of conduction electrons increases the resistance of the spin valve sensor and a decrease in scattering of the conduction electrons decreases the resistance of the spin valve sensor. Changes in resistance of the spin valve sensor is a function of cos Θ, where Θ is the angle between the magnetic moments of the pinned and free layers. When a sense current is conducted through the spin valve sensor, resistance changes cause potential changes that are detected and processed as playback signals from the rotating magnetic disk. The sensitivity of the spin valve sensor is quantified as magnetoresistance or magnetoresistive coefficient dr/R where dr is the change in resistance of the spin valve sensor from minimum resistance (magnetic moments of free and pinned layers parallel) to maximum resistance (magnetic moments of the free and pinned layers antiparallel) and R is the resistance of the spin valve sensor at minimum resistance. Because of the high magnetoresistance of a spin valve sensor it is sometimes referred to as a giant magnetoresistive (GMR) sensor.

FIG. **1A** shows a prior art SV sensor **100** comprising a free layer (free ferromagnetic layer) **110** separated from a pinned layer (pinned ferromagnetic layer) **120** by a non-magnetic, electrically-conducting spacer layer **115**. The magnetization of the pinned layer **120** is fixed by an antiferromagnetic (AFM) layer **130**.

FIG. **1B** shows another prior art SV sensor **150** with a flux keepered configuration. The SV sensor **150** is substantially identical to the SV sensor **100** shown in

FIG. **1A** except for the addition of a keeper layer **152** formed of ferromagnetic material separated from the free layer **110** by a non-magnetic spacer layer **154**. The keeper layer **152** provides a flux closure path for the magnetic field from the pinned layer **120** resulting in reduced magnetostatic interaction of the pinned layer **120** with the free layer **110**. U.S. Pat. No. 5,508,867 granted to Cain et al., incorporated herein by reference, discloses a SV sensor having a flux keepered configuration.

Another type of spin valve sensor is an antiparallel (AP) spin valve sensor. The AP pinned spin valve sensor differs from the simple spin valve sensor in that the AP pinned spin valve sensor has an AP pinned structure that has first and second AP pinned layers instead of a single pinned layer. An AP coupling layer is sandwiched between the first and second AP pinned layers. The first AP pinned layer has its magnetic moment oriented in a first direction, typically by exchange coupling to an antiferromagnetic pinning layer. The second AP pinned layer is positioned towards the free layer and is antiparallel coupled to the first AP pinned layer because of the minimal thickness (in the order of 8 Å) of the AP coupling layer between the first and second AP pinned layers. Accordingly, the magnetic moment of the second AP pinned layer is oriented in a second direction that is antiparallel to the direction of the magnetic moment of the first AP pinned layer.

Referring to FIG. **2A**, a typical AP spin valve sensor **200** comprises a free layer **210** separated from a laminated AP-pinned layer structure **220** by a nonmagnetic, electrically-conducting spacer layer **215**. The magnetization of the laminated AP-pinned layer structure **220** is fixed by an AFM layer **230**. The laminated AP-pinned layer structure **220** comprises a first ferromagnetic layer **222** and a second ferromagnetic layer

226 separated by an antiparallel coupling layer (APC) **224** of nonmagnetic material. The two ferromagnetic layers **222, 226** (FM_1 and FM_2) in the laminated AP-pinned layer structure **220** have their magnetization directions oriented antiparallel, as indicated by the arrows **223, 227** (arrows pointing out of and into the plane of the paper respectively).

The AP pinned structure is preferred over the single pinned layer because the magnetic moments of the first and second AP pinned layers of the AP pinned structure subtractively combine to provide a net magnetic moment that is less than the magnetic moment of the single pinned layer. The direction of the net moment is determined by the thicker of the first and second AP pinned layers. A reduced net magnetic moment equates to a reduced demagnetization (demag) field from the AP pinned structure. Since the antiferromagnetic exchange coupling is inversely proportional to the net pinning moment, this increases exchange coupling between the first AP pinned layer and the pinning layer. The AP pinned spin valve sensor is described in U.S. Pat. No. 5,465,185 to Heim and Parkin which is incorporated by reference herein.

The AP pinned structure is also preferred because the AP pinned layers, by virtue of their self-pinning character, retain their pinned orientation in the absence of an antiferromagnetic pinning layer. Thus, the antiferromagnetic pinning layer is not a necessary component of the AP spin valve sensor. The total thickness of the AP spin valve sensor is significantly reduced without the antiferromagnetic pinning layer. Further, current shunting through the antiferromagnetic pinning layer is eliminated in current in plane (CIP) heads. The result is that the dr/R (signal) is increased.

Increasing the GMR of spin valve sensor is very critical to meet the amplitude requirements of future products. Currently, a number of seedlayer structures have been

used for spin valve structures to enhance their properties. One of these seedlayer structures is Al_2O_3/NiFeCr(25 to 50Å)/NiFe(8 to 15Å)/PtMn(4 to 30Å)/AP-1 (CoFe).... The dr/R of a self pinned sensor from this seedlayer structure is on the order of 15%. What is needed is a new structure with improved dr/R. What is also needed is a new AP spin valve sensor with an AP pinned structure having improved magnetostriction for increased stability of the sensor.

SUMMARY OF THE INVENTION

The present invention overcomes the drawbacks and limitations described above by providing a magnetic head structure having a new seedlayer structure which maximizes GMR signal of the head and/or magnetostriction of the pinned layers. For instance, the new structure shows an increase in dr/R from the current 15% level to as high as 18% or more.

Accordingly, a magnetic head according to one embodiment includes a seed layer structure comprising Al_2O_3, Ta, and NiFeCr seed layers. An antiparallel (AP) pinned layer structure is formed above the NiFeCr seed layer. A free layer is positioned above the AP pinned layer structure. Preferably, the AP pinned layer structure includes at least two pinned layers having magnetic moments that are self-pinned antiparallel to each other, the pinned layers being separated by an AP coupling layer.

In one embodiment, the AP pinned layers are constructed of CoFe and Co, with the pinned layer closest to the seed layer structure preferably including the CoFe. In another embodiment, the AP pinned layers are both constructed of Co. In yet another embodiment, the AP pinned layers are both constructed of CoFe.

In an embodiment, the AP pinned layers are constructed of materials selected to maximize a magnetostriction of the AP pinned layers. In a further embodiment, a thickness of the NiFeCr seed layer is selected to maximize a GMR signal. Preferably, the head has at least a 10% stronger GMR signal over a head having a substantially similar structure (similar materials and/or thicknesses) except for the seed layers. Also

preferably, the head has at least a 10% stronger GMR signal over a head having a substantially similar structure except for materials used to form the pinned layers.

BRIEF DESCRIPTION OF THE DRAWINGS

For a fuller understanding of the nature and advantages of the present invention, as well as the preferred mode of use, reference should be made to the following detailed description read in conjunction with the accompanying drawings.

FIG. **1A** is an air bearing surface view, not to scale, of a prior art spin valve (SV) sensor.

FIG. **1B** is an air bearing surface view, not to scale, of a prior art keepered SV sensor.

FIG. **2A** is an air bearing surface view, not to scale, of a prior art AP spin valve sensor.

FIG. **2B** is a perspective view, not to scale, of a prior art AP spin valve sensor.

FIG. **3** is a simplified drawing of a magnetic recording disk drive system.

FIG. **4** is a partial view of the slider and a merged magnetic head.

FIG. **5** is a partial ABS view, not to scale, of the slider taken along plane **5-5** of FIG. **4** to show the read and write elements of the merged magnetic head.

FIG. **6** is an enlarged isometric illustration, not to scale, of the read head with a spin valve sensor.

FIG. **7** is a chart illustrating properties of several new self pinned spin valve structures

FIG. **8** is an ABS illustration, not to scale, of a GMR sensor in accordance with Heads A-E of FIG. **7**.

FIG. **9** depicts an ABS view, not to scale, of a GMR sensor constructed in accordance with Head F of FIG. **7**.

FIG. **10** depicts an ABS view, not to scale, of a GMR sensor constructed in accordance with Head G of FIG. **7**.

FIG. **11** depicts an ABS view of a standard GMR sensor constructed in accordance with the Standard Head of FIG. **7**.

BEST MODE FOR CARRYING OUT THE INVENTION

The following description is the best embodiment presently contemplated for carrying out the present invention. This description is made for the purpose of illustrating the general principles of the present invention and is not meant to limit the inventive concepts claimed herein.

Referring now to FIG. **3**, there is shown a disk drive **300** embodying the present invention. As shown in FIG. **3**, at least one rotatable magnetic disk **312** is supported on a spindle **314** and rotated by a disk drive motor **318**. The magnetic recording on each disk is in the form of an annular pattern of concentric data tracks (not shown) on the disk **312**.

At least one slider **313** is positioned near the disk **312**, each slider **313** supporting one or more magnetic read/write heads **321**. More information regarding such heads **321** will be set forth hereinafter during reference to FIG. **4**. As the disks rotate, slider **313** is moved radially in and out over disk surface **322** so that heads **321** may access different tracks of the disk where desired data are recorded. Each slider **313** is attached to an actuator arm **319** by means way of a suspension **315**. The suspension **315** provides a slight spring force which biases slider **313** against the disk surface **322**. Each actuator arm **319** is attached to an actuator means **327**. The actuator means **327** as shown in FIG. **3** may be a voice coil motor (VCM). The VCM comprises a coil movable within a fixed magnetic field, the direction and speed of the coil movements being controlled by the motor current signals supplied by controller **329**.

During operation of the disk storage system, the rotation of disk **312** generates an air bearing between slider **313** and disk surface **322** which exerts an upward force or lift on the slider. The air bearing thus counter-balances the slight spring force of suspension **315** and supports slider **313** off and slightly above the disk surface by a small, substantially constant spacing during normal operation.

The various components of the disk storage system are controlled in operation by control signals generated by control unit **329**, such as access control signals and internal clock signals. Typically, control unit **329** comprises logic control circuits, storage means and a microprocessor. The control unit **329** generates control signals to control various system operations such as drive motor control signals on line **323** and head position and seek control signals on line **328**. The control signals on line **328** provide the desired current profiles to optimally move and position slider **313** to the desired data track on disk **312**. Read and write signals are communicated to and from read/write heads **321** by way of recording channel **325**.

The above description of a typical magnetic disk storage system, and the accompanying illustration of FIG. **3** are for representation purposes only. It should be apparent that disk storage systems may contain a large number of disks and actuators, and each actuator may support a number of sliders.

FIG. **4** is a side cross-sectional elevation view of a merged magnetic head **400**, which includes a write head portion **402** and a read head portion **404**, the read head portion employing a dual spin valve sensor **406** of the present invention. FIG. **5** is an ABS view of FIG. **4**. The spin valve sensor **406** is sandwiched between nonmagnetic electrically insulative first and second read gap layers **408** and **410**, and the read gap

layers are sandwiched between ferromagnetic first and second shield layers **412** and **414**. In response to external magnetic fields, the resistance of the spin valve sensor **406** changes. A sense current (I_s) conducted through the sensor causes these resistance changes to be manifested as potential changes. These potential changes are then processed as readback signals by the processing circuitry **329** shown in FIG. **3**.

The write head portion **402** of the magnetic head **400** includes a coil layer **422** sandwiched between first and second insulation layers **416** and **418**. A third insulation layer **420** may be employed for planarizing the head to eliminate ripples in the second insulation layer caused by the coil layer **422**. The first, second and third insulation layers are referred to in the art as an "insulation stack". The coil layer **422** and the first, second and third insulation layers **416, 418** and **420** are sandwiched between first and second pole piece layers **424** and **426**. The first and second pole piece layers **424** and **426** are magnetically coupled at a back gap **428** and have first and second pole tips **430** and **432** which are separated by a write gap layer **434** at the ABS. Since the second shield layer **414** and the first pole piece layer **424** are a common layer this head is known as a merged head. In a piggyback head an insulation layer is located between a second shield layer and a first pole piece layer. First and second solder connections (not shown) connect leads (not shown) from the spin valve sensor **406** to leads (not shown) on the slider **313** (FIG. 3), and third and fourth solder connections (not shown) connect leads (not shown) from the coil **422** to leads (not shown) on the suspension.

FIG. **6** is an enlarged isometric ABS illustration of the read head **400** shown in FIG. **4**. The read head **400** includes the spin valve sensor **406**. First and second hard bias and lead layers **602** and **604** are connected to first and second side edges **606** and **608** of

the spin valve sensor. This connection is known in the art as a contiguous junction and is fully described in U.S. Pat. 5,018,037 which is incorporated by reference herein. The first hard bias and lead layers **602** include a first hard bias layer **610** and a first lead layer **612** and the second hard bias and lead layers **604** include a second hard bias layer **614** and a second lead layer **616**. The hard bias layers **610** and **614** cause magnetic fields to extend longitudinally through the spin valve sensor **406** for stabilizing the magnetic domains therein. The spin valve sensor **406** and the first and second hard bias and lead layers **602** and **604** are located between the nonmagnetic electrically insulative first and second read gap layers **408** and **410**. The first and second read gap layers **408** and **410** are, in turn, located between the ferromagnetic first and second shield layers **412** and **414**.

The present invention provides a sensor structure having a new seedlayer structure which increases the dr/R of self pinned spin valve structures from the current 15% level to as high as 18% or more. Studies were performed with different seedlayers such as a) Al_20_3/Ta/NiFeCr/PtMn, b) Al_20_3/Ta/PtMn, c) Al_20_3/Ta/Cu /PtMn, d) Al_20_3/Ta, and e) Al_20_3/Ta/Cu. Of all of these seedlayers, the Al_20_3/Ta/NiFeCr/... structure gave results superior to all other seedlayer structures including standard structures (i.e., those including an AFM layer). The signal increase from 15% to ~18% is an enormous increase for GMR. The experiments also show that the positive magnetostriction of the pinned layers are also preserved for successful pinning. In these new structures, the AFM layer (e.g., PtMn) is completely removed from the SV structure, resulting in a significant reduction of net sensor thickness. Elimination of the AFM layer also increases signal due to reduced shunting of the current through the AFM layer.

FIG. **7** is a chart **700** illustrating properties of several new self pinned spin valve structures as a function of NiFeCr thickness and/or pinned layer composition. Each of these exemplary structures is discussed in detail below. As shown in FIG. **7**, the new seedlayer of Al_2O_3/Ta/NiFeCr improves both dr/R and magnetostriction over a standard head.

Referring again to FIG. **7**, it can be seen that the thickness of the NiFeCr seed layer can be tuned to maximize the GMR signal (dr/R). For example, the 40Å NiFeCr seed layer of Head D provides an 18% GMR, which is a 20% improvement over the standard self pinned spin valve structures (e.g., Standard Head, 15% GMR).

As also shown in FIG. **7**, the materials used to construct the pinned layers can also be selected to provide stronger magnetostriction, and therefore stronger pinning of the pinned layers. Particularly, pinned layers (AP1, AP2) of CoFe nearest the seed layer and Co provide much improved magnetostriction over standard CoFe/CoFe pinned layers. The pinning field (Hk) is generally provided by the following equation:

$$Hk = 2 \cdot K_\lambda / M_s \qquad \textit{Equation 1}$$

where K_λ is the anisotropy constant and M_s is the saturation magnetization.

K_λ is determined by the following equation:

$$K_\lambda = 3/2 \cdot \sigma \cdot \lambda \qquad \textit{Equation 2}$$

where σ is a measure of the stress and λ is the magnetostriction.

Per Equation 1, increasing the K_λ increases the pinning field. Per Equation 2, increasing either stress or magnetostriction increases K_λ. For example, doubling λ doubles the Hk.

Referring to FIG. 7, Head F has a magnetostriction of about 24×10^{-6}. This is about a 40% increase over the Standard Head, and about twice as high as the magnetostriction of the pinned layers of Head G having a NiFeCr seed layer of the same thickness. Thus, per Equations 1 and 2, the pinning of the pinned layers of Head F will be much stronger than the pinning of Head G.

Thus, the concepts presented herein allow the designer to maximize signal, pinning, or both by selecting particular materials and their thicknesses. Thus, if the designer wants high magnetostriction in the head, and thus better pinning, the pinned layers can both be constructed of Co. If the designer prefers a higher signal, the pinned layers can be constructed of CoFe and Co, as in Heads A-E. As a case in point, Head B has a magnetostriction of about 19×10^{-6}, which is lower than that of Head F, but Head B has a higher dr/R for the same thickness of the NiFeCr layer.

In the following description, the width of the layers (W) refers to the track width. The sensor height is in a direction into the face of the paper. Unless otherwise described, thicknesses of the individual layers are taken perpendicular to the plane of the associated layer and are provided by way of example only and may be larger and/or smaller than those listed. Similarly, the materials listed herein are provided by way of example only, and one skilled in the art will understand that other materials may be used without

straying from the spirit and scope of the present invention. Conventional processes can be used for form the structures except where otherwise noted.

Heads A-E

FIG. **8** depicts an ABS view of a CIP GMR sensor **800** constructed in accordance with Heads A-E of FIG. **7**. As shown in FIG. **8**, a first insulative layer (G1) **802** is formed on a substrate (not shown). The first insulative layer **802** can be of any suitable material, such as alumina (Al_2O_3).

Seed layers are formed on the first insulative layer **802** preferably by deposition. The seed layers aid in creating the proper growth structure of the layers above them, and using the particular materials described herein, have also been found to provide definable characteristics to the head, including dr/R and magnetostriction. While not wishing to be bound by any particular theory, the inventor believes that the seed layer structure described herein causes the microstructure of the growing film to form in a certain way that results in increased dr/R and magnetostriction. The materials formed in a stack from the first insulative layer **802** are a layer of Al_2O_3 (SL1) **804**, a layer of Ta (SL2) **806**, and a layer of NiFeCr (SL3) **808**. Illustrative thicknesses of these materials are Al_2O_3 (30Å), Ta (30Å), and NiFeCr (10-75Å). Refer to FIG. **7** for the various thicknesses of the NiFeCr layer **808** in the heads discussed herein. Note that the thicknesses of any of these layers **804-808** can be varied, as mentioned above.

Then an antiparallel (AP) pinned layer structure **812** is formed above the seed layers. As shown in FIG. **8**, first and second AP pinned magnetic layers, (AP1) and (AP2) **814**, **816**, are separated by a thin layer of an antiparallel coupling (APC) material

818 such that the magnetic moments of the AP pinned layers **814, 816** are pinned antiparallel to each other. This magnetic coupling through the Ru spacer **818** causes the pinned layers **814, 816** to have antiparallel-oriented magnetizations. The pinned layer structure **812** in turn stabilizes the free layer (described below) via exchange coupling.

In the embodiment, the pinned layers **814, 816** are CoFe, such as $CoFe_{10}$ (90% Co, 10% Fe) or $CoFe_{50}$ (50% Co, 50% Fe). separated by a Ru layer **818**. Illustrative thicknesses of the first and second pinned layers **814, 816** are between about 10Å and 25Å. The Ru layer **818** can be about 3-10Å, ideally about 8Å.

A first spacer layer (SP1) **820** is formed above the pinned layer structure **812**. Illustrative materials for the first spacer layer **820** include Cu, CuO_x, Cu/$CoFeO_x$/Cu stack, etc.

A free layer structure **822** is formed above the first spacer layer **820**. The magnetic moment of the free layer structure **822** is soft and so is susceptible to reorientation from external magnetic forces, such as those exerted by data on disk media. The relative motion of magnetic orientation of the free layer structure **822** when affected by data bits on disk media creates variations in the sensing current flowing through the sensor **800**, thereby creating the signal. Exemplary materials for the free layer structure **822** are CoFe, NiFe, a CoFe/NiFe stack (FL1, FL2) **824, 826** as shown, etc. An illustrative thickness of the free layer structure **822** is about 10-40Å.

A cap (CAP) **828** is formed above the free layer **822**. Exemplary materials for the cap **828** are Ta, Ta/Ru stack, etc. An illustrative thickness of the cap **828** is 20-50Å. In the embodiment shown in FIG. 7, the cap **828** is 40Å.

A second insulative layer (G2) **830** is formed above the cap **828**. Hard bias and leads **832** of conventional materials are formed on both sides of the sensor **800**.

Head F

FIG. **9** depicts an ABS view of GMR sensor **900** constructed in accordance with Head F of FIG. **7**. The GMR sensor **900** generally has the same configuration as the structure shown in FIG. **8**, except that pinned layers **814**, **816** are each formed of Co.

Head G

FIG. **10** depicts an ABS view of GMR sensor **1000** constructed in accordance with Head G of FIG. **7**. The GMR sensor **1000** generally has the same configuration as the structure shown in FIG. **8**, except that pinned layers **814**, **816** are each formed of CoFe.

One approach to stabilize the free layer **822** in all above embodiments is to use contiguous hard bias layers at the track edges of the sensor. For a CIP GMR sensor, these hard bias layers would be in electrical contact with the sensor stack.

Standard Head

FIG. **11** depicts an ABS view of a standard GMR sensor **1100** constructed in accordance with the Standard Head of FIG. **7**. The GMR sensor **1100** generally has the same configuration as the structure shown in FIG. **10**, except that the materials formed in a stack from the first shield layer **802** are a layer of Al_2O_3 (SL1) **1104**, a layer of NiFeCr (SL2) **1106**, a layer of NiFe (SL3) **1108** and a layer of PtMn (SL4) **1110**. Illustrative

thicknesses of these materials are Al_2O_3 (30Å), NiFeCr (25Å), NiFe (8Å), and PtMn (30Å).

While various embodiments have been described above, it should be understood that they have been presented by way of example only, and not limitation. For example, the structures and methodologies presented herein are generic in their application to all GMR heads. Thus, the breadth and scope of a preferred embodiment should not be limited by any of the above-described exemplary embodiments, but should be defined only in accordance with the following claims and their equivalents.